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UNIVERSITÄT FREIBURG

Algorithms for Radio Networks

Localization

University of FreiburgTechnical Faculty
Computer Networks and Telematics
Prof. Christian Schindelhauer

CoNe Freiburg

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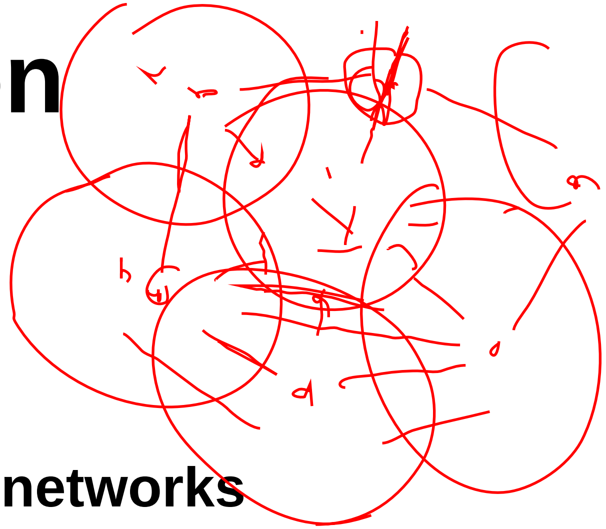
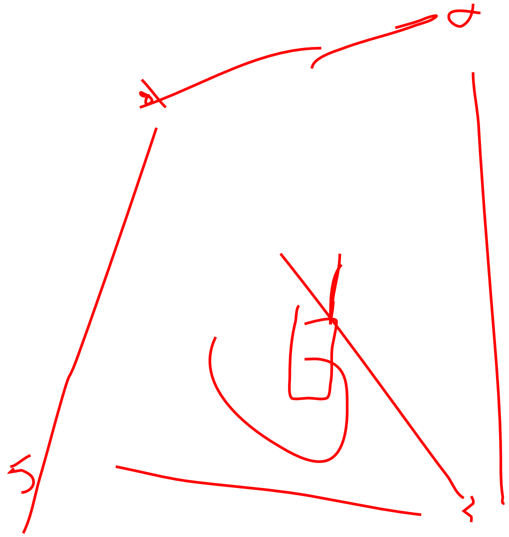
Coarse Localization Techniques



- **Hop-distance**
  - **in dense ad hoc networks or wireless sensor networks**
  - **approximate position by the number of hops to anchor points**
- **Overlapping connections**
  - **position at the intersection of the received transmission circuits**
- **Localization point in the triangle**
  - **determination of triangles of anchor points**
    - **in which the node lies**
  - **overlap provides approximate position**
- **“Fingerprinting” of signal strength measures**



Localization methods

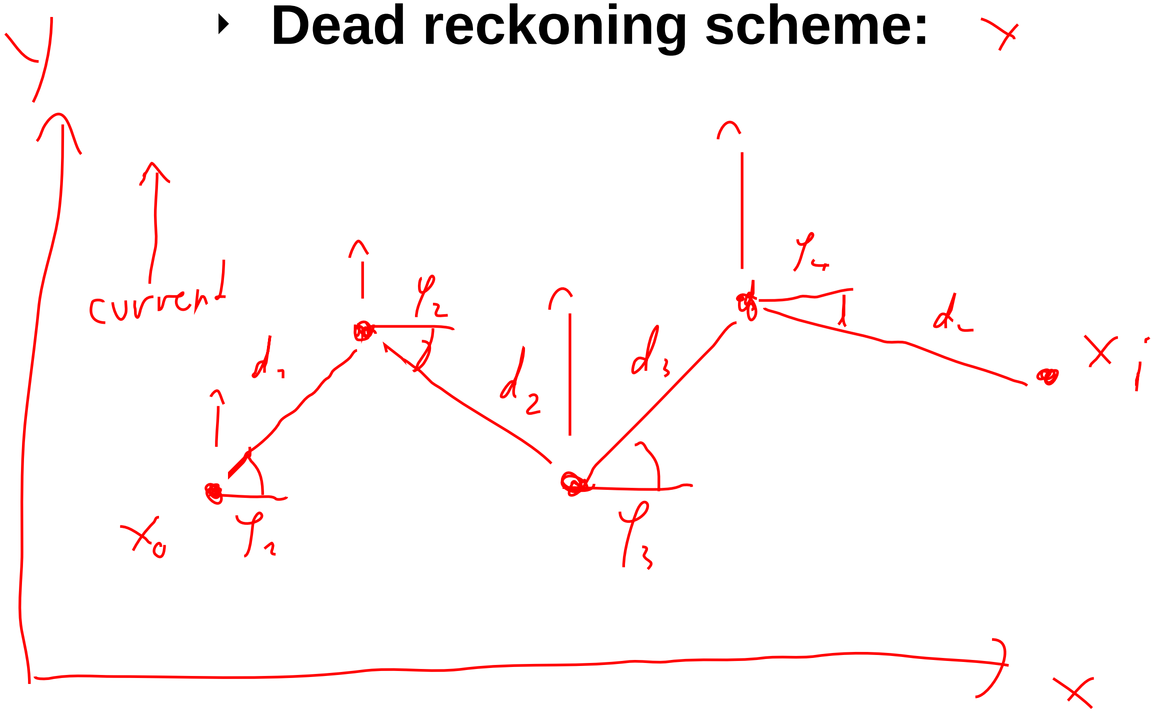
- **Dead Reckoning: Relative localization depending on course and traveled distance**
- **Triangulation: Calculate the intersection of angular bearings**
- **Trilateration: Calculate the intersection of three range measurements (circles)**
- **Multilateration with *absolute* ranges: Calculate the intersection of *at least four* range measurements**
  - **In the plane: circles, in space: spheres**
  - **May be over-determined equation system**
- **Multilateration with *relative* ranges: Hyperbolic multilateration**
  - **Multilateration with unknown send time**
  - **Calculate intersection of hyperbolas / hyperboloids**

Dead Reckoning

- **Relative vector navigation, vectors of orientation** ϕ_i **and distance** d_i
- **Animals: “path integration” by special regions in hippocampus of desert ants (Wehner, 2003)**
- **Dead reckoning scheme:** x

Relative angle

$\varphi_i = \varphi_{i-1} + \alpha_i$



Recursive

$x_i = x_{i-1} + d_i \cdot \cos \varphi_i$

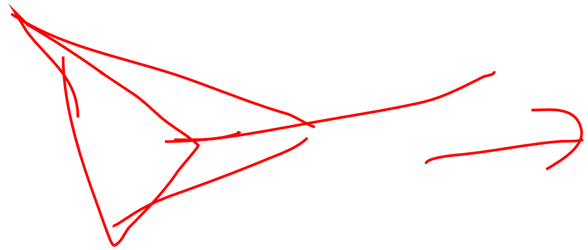
$y_i = y_{i-1} + d_i \cdot \sin \varphi_i$

Direct

$x_i = x_0 + \sum_{i=1}^{n} d_i \cos \varphi_i$

$y_i = x_0 + \sum_{i=1} d_i \sin \varphi_i$

Dead Reckoning



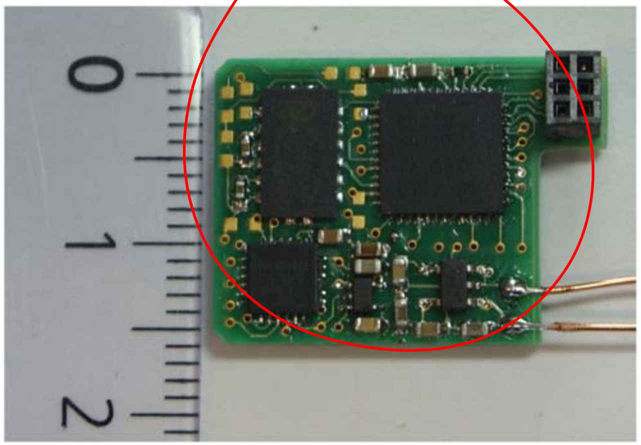
- Example: Navigation of ships / airplanes
  - if course is known (compass)
  - if traveled distance is known (ship log, pitot tube)
- Prone to drift (water current, wind, wheel slip)
- Errors add up over time

Inertial Navigation

- Consider orientation and traveled distance as direction vector s_t at time t.
- What if only acceleration a_t is measured?
  - *Inertial navigation*, double integration

$$\vec{s}(t) = \int\!\!\int \vec{a}(t)dt^2 + \vec{s_0} + \vec{v_0} \cdot t$$

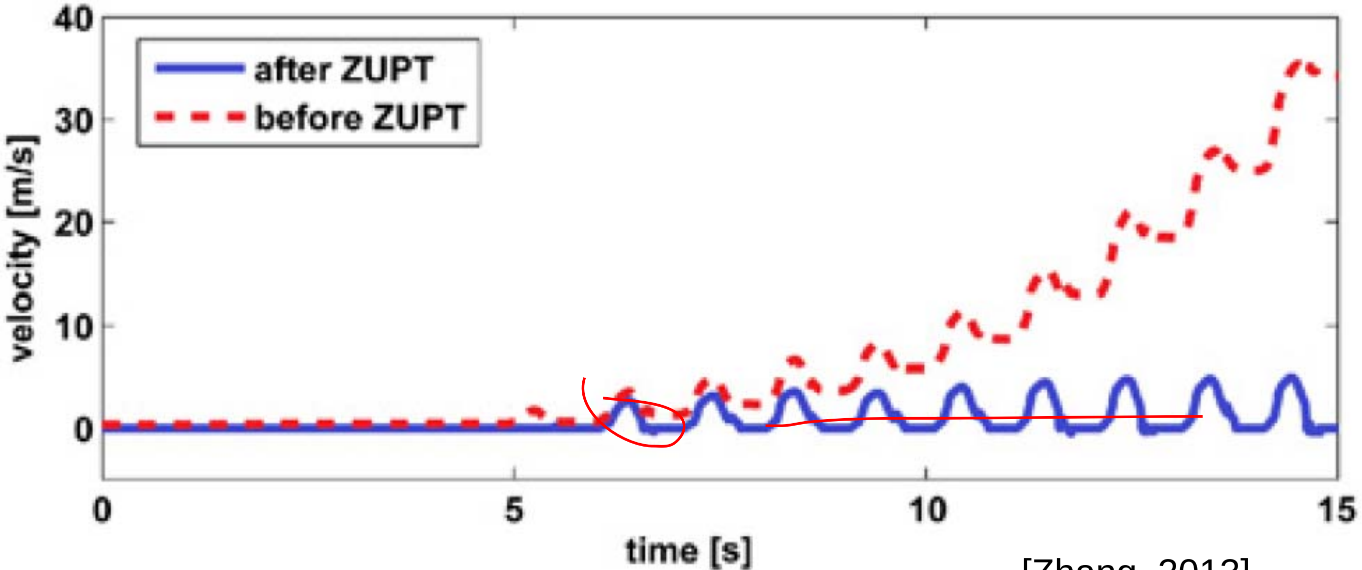
  - Often also rotation is measured (angular velocity)
- Combine accelerometer, gyroscope, and compass:
  - Inertial Measurement Unit (IMU)



[F. Höflinger, 2013]

Inertial Navigation

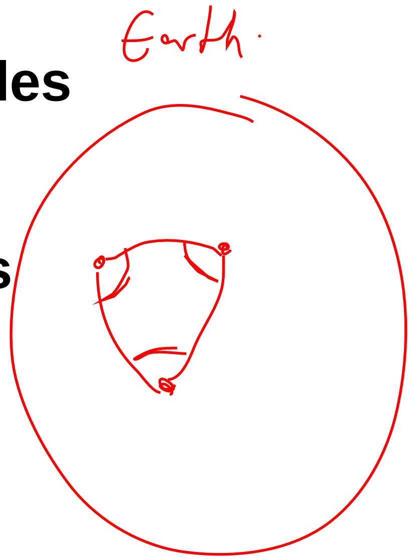
- Foot-mounted MEMS-IMU
  - Errors add up over time
- Compensation: Zero velocity update
  - Detect footstep
  - Translation velocity is zero at this moment!

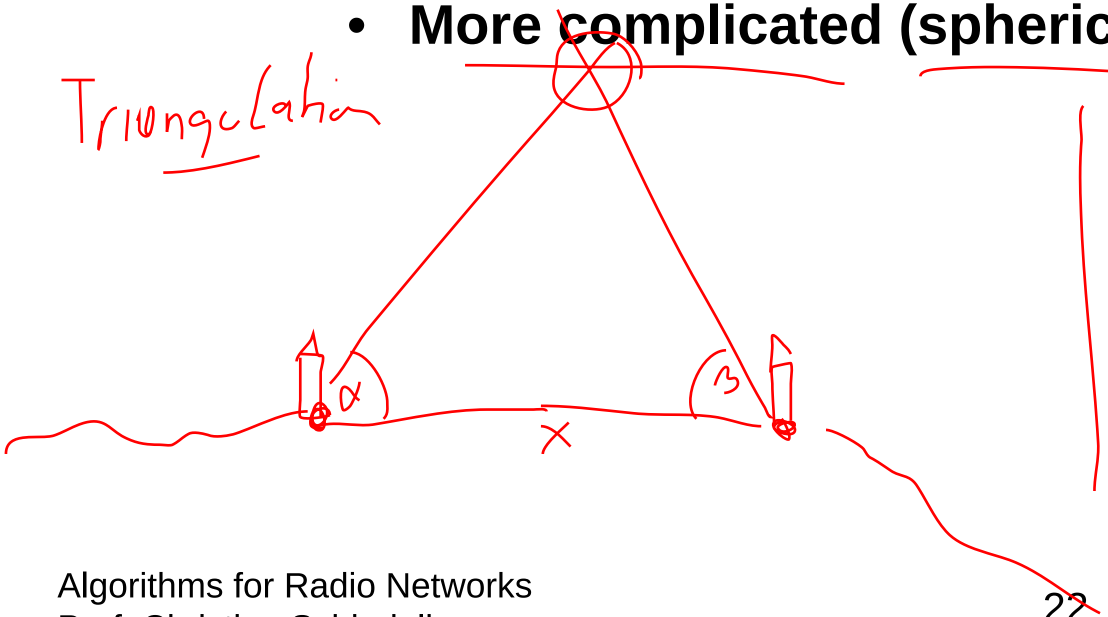


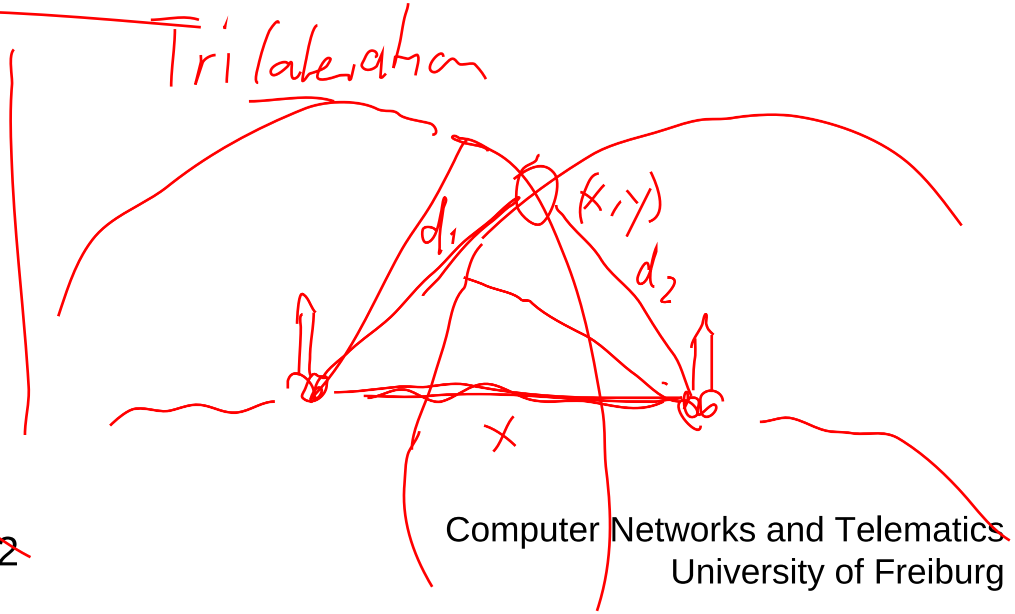
[Zhang, 2013]

Triangulation

- Given a side of known length and two adjacent angles
- In the plane:
  - Calculate the intersection point of the other sides
  - Duality with trilateration: Triangle congruency (angle-side-angle) ←→ (side-side-side)
- On earth surface:
  - More complicated (spherical trigonometry)



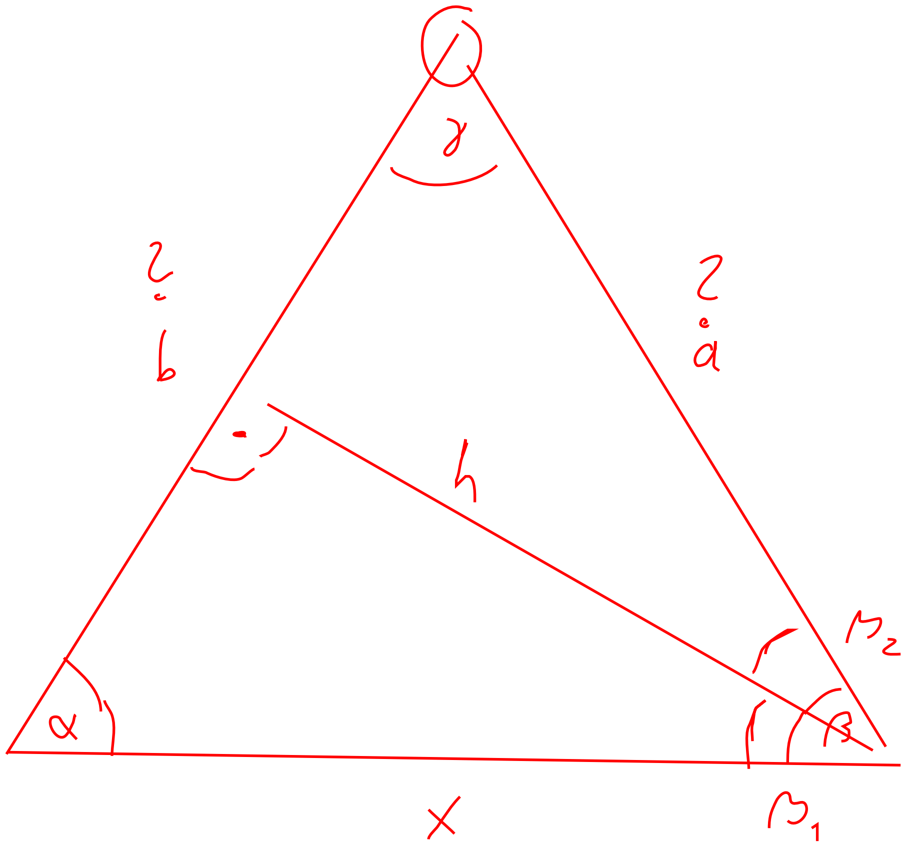




Triangulation

$\Longleftrightarrow$

Trilateration



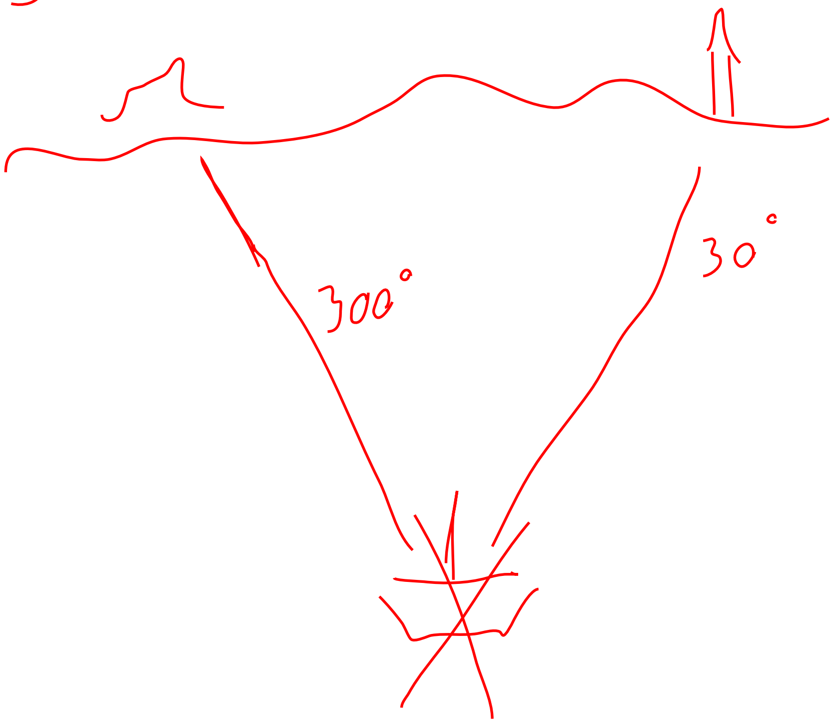
$$\frac{h}{a} = \cos \beta_2$$

$$\frac{h}{x} = \cos \beta_1$$

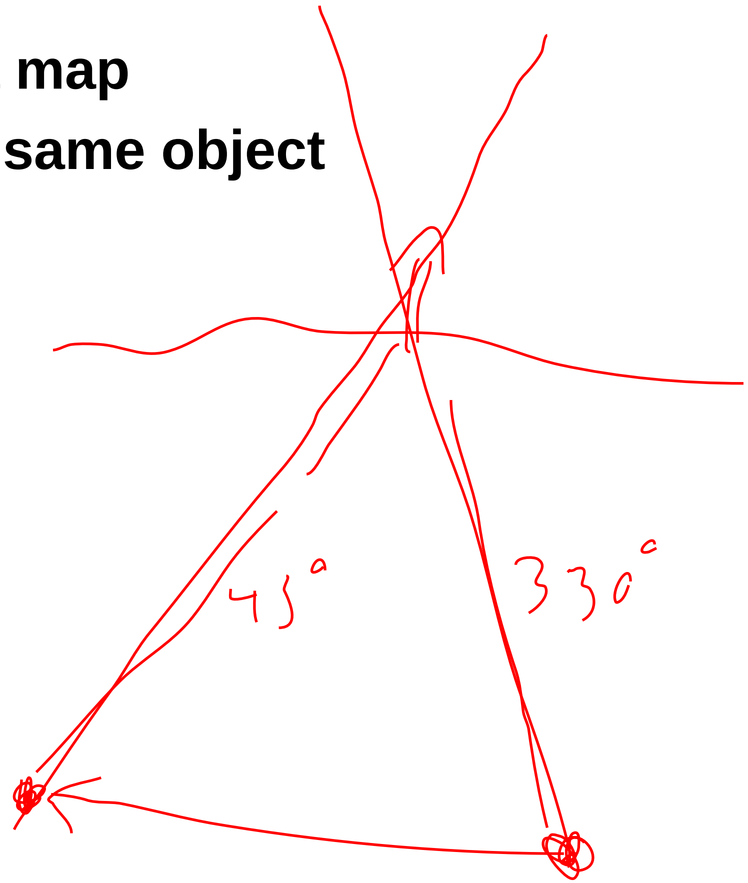
Triangulation

- **Example: Navigation of ships / airplanes (cross bearing triangulation)**
  - **1) Bearings of two objects on a map**
    2) Time-shifted bearings of the same object

1)

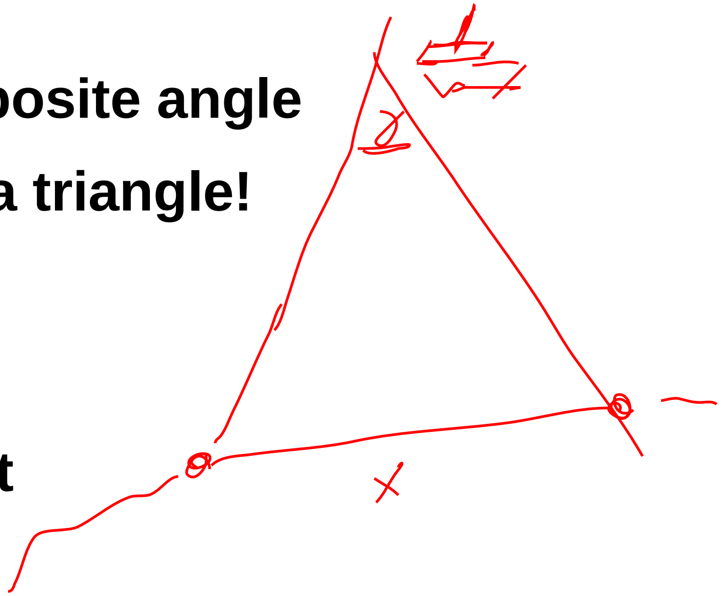


2)

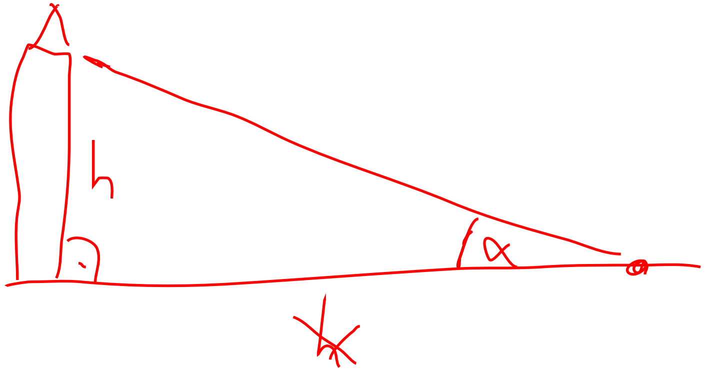


Triangulation

- Given a side of known length and the opposite angle
  - Triangle congruency: Does not define a triangle!
  - What else is possible?



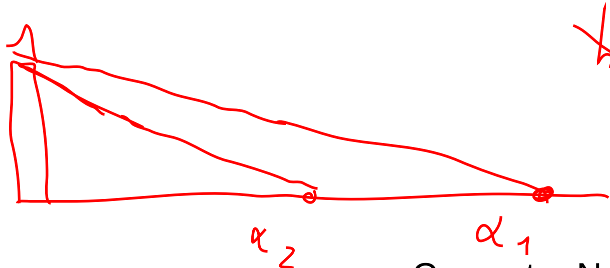
- Given a lighthouse of known height h
  - Measurement of angle ϕ, use a sextant
  - Calculation of distance d = h / tan(ϕ)
  - Measurement of lighthouse bearing
  - ➔ position in polar coordinates



- Height of lighthouse not known
  - Sail towards lighthouse

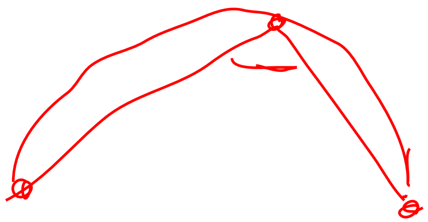
$$d = \frac{h}{\tan \alpha_1}$$

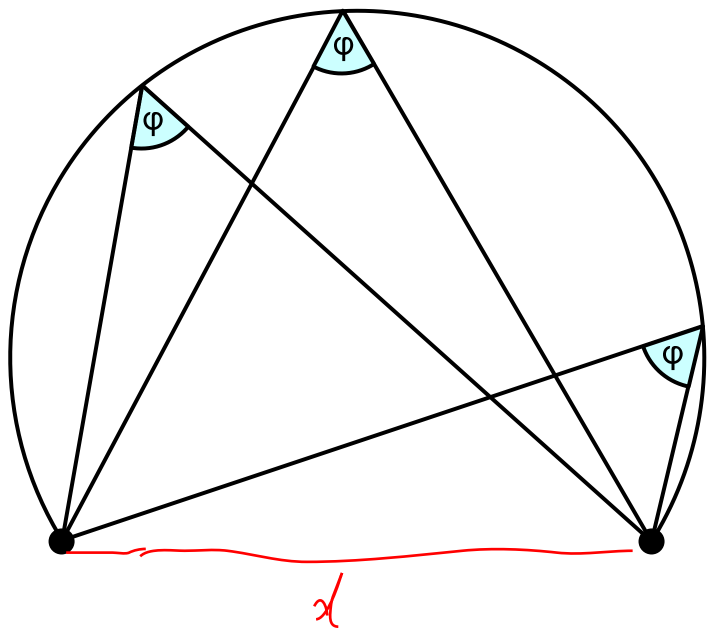
$$d = \frac{h}{\tan \alpha_2}$$



Triangulation

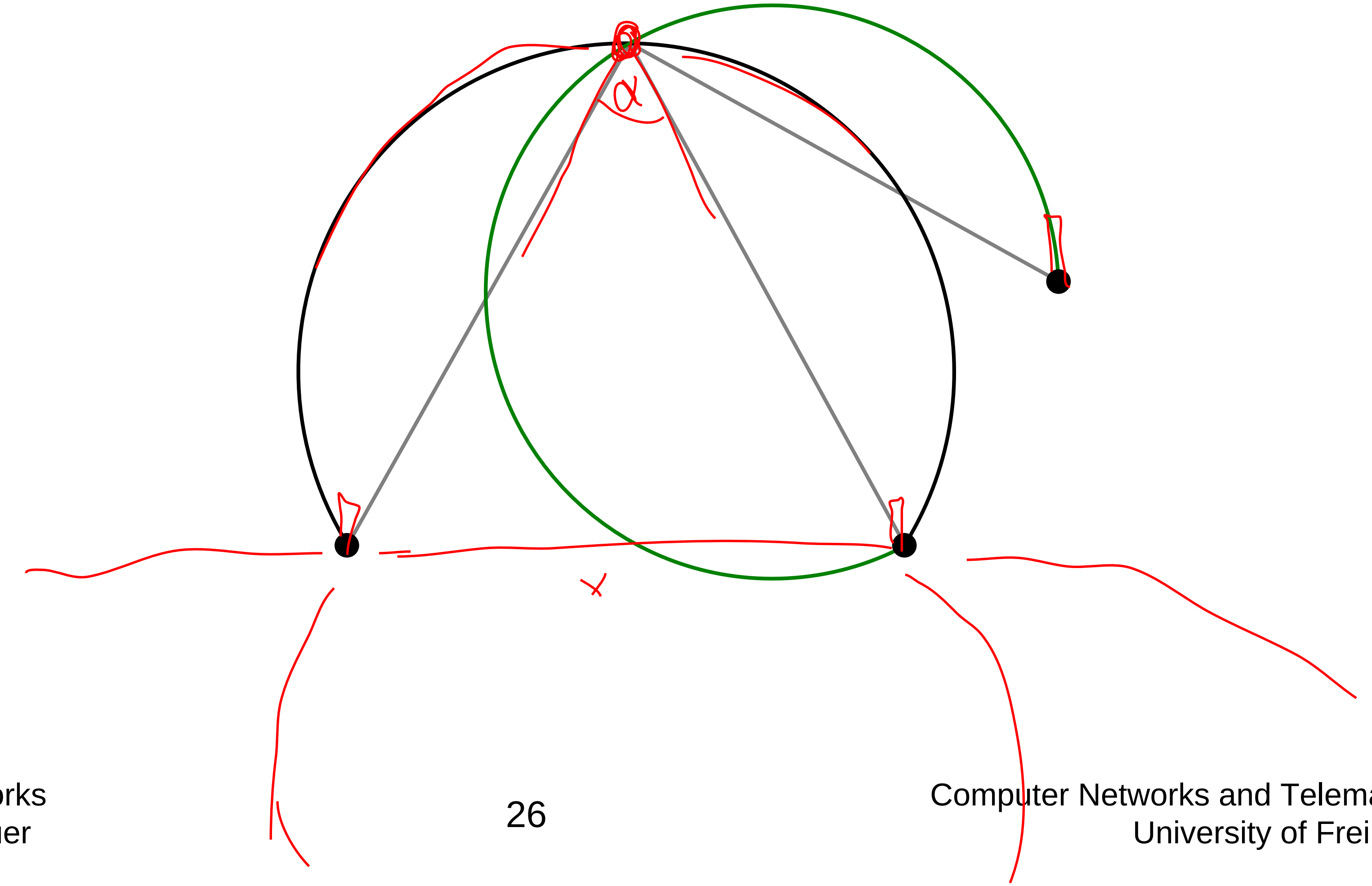
- **Given a side of known length and the opposite angle**
  - **Measure angle ϕ of two landmarks (by theodolite or by laser scanner)**
  - **If $\phi = 90^\circ$: Ship's position resides on Thales' circle**
  - **Other angles: generalization of Thales' circle**
  - **Circle of equal angles ("Fasskreisbogen")**





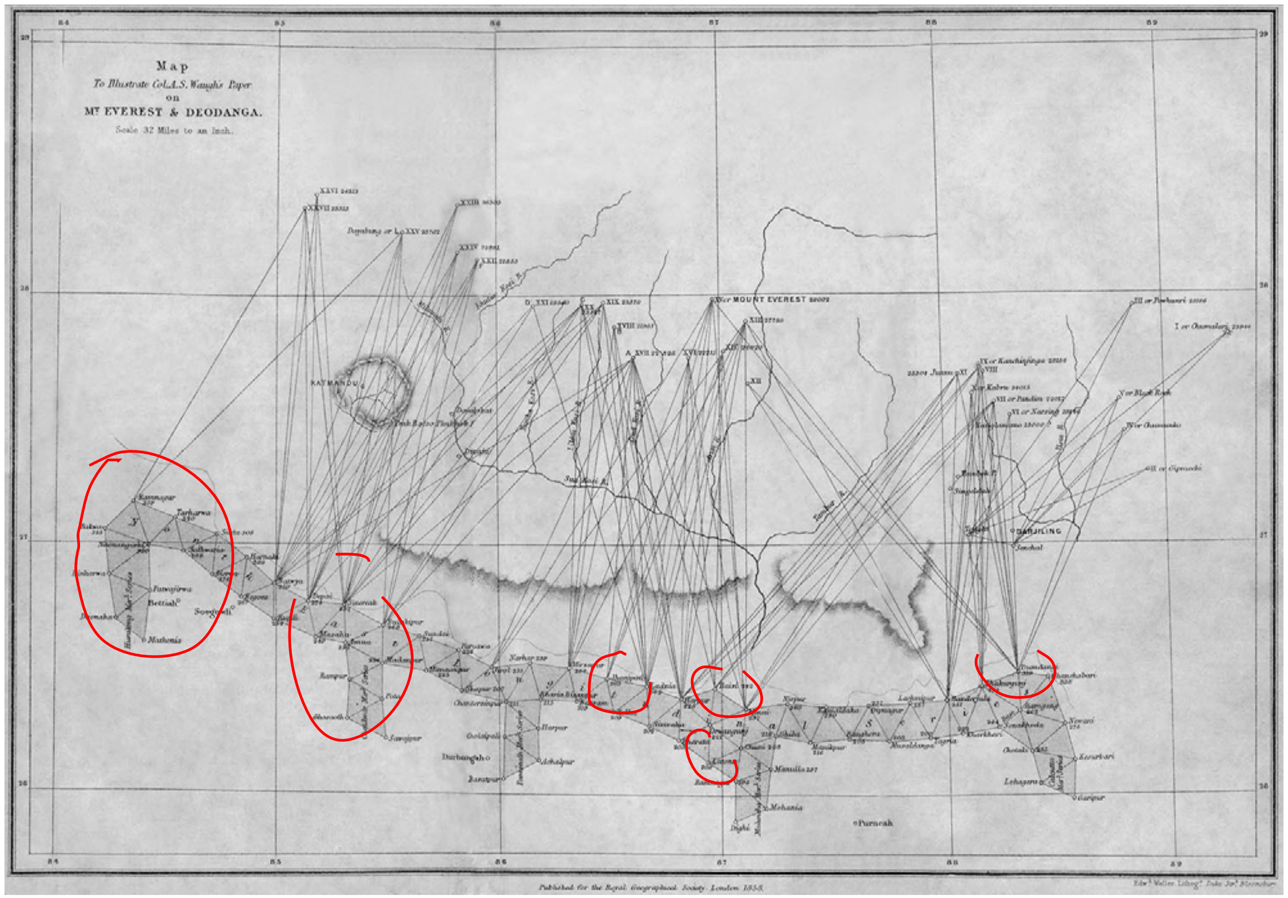
Triangulation

- Given a side of known length and the opposite angle
  - Calculate position by a third landmark



Triangulation

- Height of Mt. Everest
  - 8,840 m above NN (Sickdhar, 1856)
  - 8,848 m (Survey of India, 1955)
  - 8,850 m (GPS, 1999)
  - 8,849 m (Radar reflectors, 2004)
  - ...



[A. Waugh, Mt. Everst & Deodanga, 1862.]

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